

High Fill-Out, Extreme Mass Ratio Overcontact Binary Systems.

X. The new discovered binary XY Leonis Minoris

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ABSTRACT

The new discovered short-period close binary star, XY LMi, was monitored photometrically since 2006. It is shown that the light curves are typical EW-type and show complete eclipses with an eclipse duration of about 80 minutes. By analyzing the complete B, V, R, and I light curves with the 2003 version of the W-D code, photometric solutions were determined. It is discovered that XY LMi is a high fill-out, extreme mass ratio overcontact binary system with a mass ratio of $q = 0.148$ and a fill-out factor of $f = 74.1\%$, suggesting that it is on the late evolutionary stage of late-type tidal-locked binary stars. As observed in other overcontact binary stars, evidence for the presence of two dark spots on both components are given. Based on our 19 epoches of eclipse times, it is found that the orbital period of the overcontact binary is decreasing continuously at a rate of $dP/dt = -1.67 \times 10^{-7}$ days/year, which may be caused by the mass transfer from the primary to the secondary or/and angular momentum loss via magnetic stellar wind. The decrease of the orbital period may result in the increase of the fill-out, and finally, it will evolve into a single rapid-rotation star when the fluid surface reaching the outer critical Roche Lobe.

Subject headings: Stars: binaries : close – Stars: binaries : eclipsing — Stars: individuals (XY LMi) – Stars: evolution

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1. Introduction

XY LMi (=TYC 2511-167-1) was recently discovered to be a short-period eclipsing binary by Bernasconi, L. in the course of asteroidal light determination (see Bernasconi & Behrend 2003) (hereafter B&B). B&B illustrated a complete CCD light curve without filters that shows a typical EW type where the light varies continuously and the depths of both minima are nearly the same. The amplitude of the light variability is only 0.38 magnitude, and the nearly flat eclipse bottom reveals that it is a total eclipsing binary. They derived a linear ephemeris,

$$Min.I = JD(HeI.)2452366.884 + 0.4368897 \times E, \quad (1)$$

which indicates XY LMi is a short-period W UMa-type binary star with a period of 10.49 hours. According to the classification of Binnendijk (1970), it belongs an A-type system where the transit minimum is deeper than the occultation one. The present name was later gave by Kazarovets (2006).

The most popular evolutionary scenario for W UMa-type binary stars is that they are formed from initially detached systems by angular momentum loss (AML) via magnetic stellar wind (Vilhu 1982; Guinan & Bradstreet 1988; Eggen & Iben 1989). Both the shrinking of the Roche lobe via AML and the expanding of the components via the evolution will result in the massive component star to fill the critical Roche lobe and the system evolves into an overcontact binary through a primary-to-secondary mass transfer. At the overcontact phase, the gradual decrease of mass ratio will make them finally evolve into rapid rotating single stars (e.g., Van't veer 1997) when the distribution of the angular momentum meets the more familiar criterion (Hut 1980) that the orbital angular momentum is less then 3 times the total spin angular momentum, i.e., $J_{rot} > 1/3 J_{orb}$. On the other hand, if the degree of overcontact is rather high, a dynamical instability will be encountered and the merge of an overcontact binary star is also inevitable (Rasio & Shapiro 1995). Therefore, high fill-out, extreme mass ratio overcontact binary stars may be the progenitors of Blue Straggler/FK Com-type stars.

The total and shallow eclipse light minima in the light curves suggest that XY LMi may be a high fill-out, extreme mass ratio overcontact binary system. This type of binary stars are at the late-evolutionary stage of W UMa-type binary systems. Therefore, it was listed in our series of photometric studies of this kind of binaries (i.e., Qian & Yang, 2004 (Paper I); Zhu et al., 2005 (Paper II); Qian et al. 2005a (Paper III); Yang et al., 2005 (Paper IV); Qian et al. (2005b) (Paper V); Qian et al. (2006) (Paper VI); Qian et al. (2007) (Paper VII); Qian et al. (2008) (Paper VIII); Yang et al. (2009) (Paper IX)). In the present paper, photometric analyses and orbital period studies of the new discovered system, XY LMi, are presented.

2. Complete CCD light curves and photometric solutions for XY Leonis Minoris

Photoelectric observations of XY LMi was made from January 26 to 30, 2008 with the 85-cm reflecting telescope at Xinglong station of the National Astronomical Observatory. The telescope was equipped with a primary-focus multicolor CCD photometer where a PI1024 BFT (Back-illuminated and Frame-Transfer) camera was used (Zhou et al. 2009). It has 1024×1024 square pixels, each subtending a projected angle on the sky of $0.''96$ and resulting in a field of view of $16.'5 \times 16.'5$. The standard Johnson-Bessel BVRI filters were used (Zhou et al. 2009) and the integration time for each image was 9 s. PHOT (measure magnitudes for a list of stars) of the aperture photometry package of IRAF ¹ was used to reduce the observed images. The coordinates of the variable star, the comparison star, and the check star are listed in Table 1. The comparison star we chose was close enough to the variable that the range of air-mass difference between both stars was very small (≈ 0.0009). Therefore, extinction correction was not made.

Complete light curves in B, V, R, and I bands were obtained and are shown in Figure 1. In all, 584 data points in B, 585 in V, 575 in R, and 565 in I were obtained. The corresponding observational data, i.e., the original HJD date and magnitude difference between XY LMi and the comparison star, are listed in Tables 2, 3, 4, and 5. As shown in Fig. 1, the light curves in 4 colors are typical EW-type where light variation is continuous and has a very small difference between the depths of the two minima. These properties reveal tidally distorted components and both of the components have similar temperature. The amplitudes of the light variation are ≈ 0.401 mag in B band, ≈ 0.383 mag in V band, ≈ 0.363 mag in R band,

¹IRAF (an acronym for Image Reduction and Analysis Facility) is a collection of software written at the National Optical Astronomy Observatory (NOAO) geared towards the reduction of astronomical images in pixel array form.

Table 1: Coordinates of XY Leonis Minoris, the comparison, and the check stars. The data come from NOMAD Catalog (Zacharias et al. 2005).

Stars	NOMAD	α_{2000}	δ_{2000}	B	V	R	(B-V)
XY LMi	1221-0223544	$10^h34^m12.3^s$	$32^\circ08'51.6''$	11.750	11.206	10.840	0.544
The comparison	1220-0213438	$10^h33^m20.2^s$	$32^\circ01'24.6''$	11.931	11.353	10.960	0.578
The check	1221-0223369	$10^h33^m30.6^s$	$32^\circ06'49.0''$	11.790	11.850	11.160	-0.060

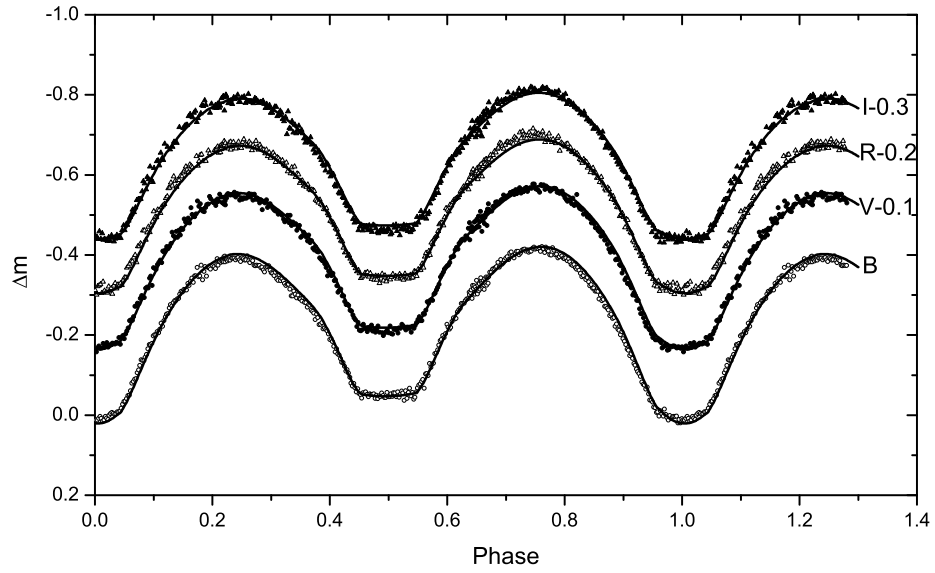


Fig. 1.— CCD photometric light curves in B, V, R, and I bands of XY Leonis Minoris obtained in January 2008. Also shown in the figure are the theoretical light curves computed with two dark spots on the primary and the secondary components, respectively.

Table 2: The original photometric data (HJD-2454400) of XY LMi in B band.

HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm
92.1825	-.307	92.2543	-.393	92.3257	-.003	92.3970	-.276	94.2028	-.386	94.2740	-.122	94.3452	-.186
92.1839	-.313	92.2553	-.386	92.3267	.002	92.3980	-.273	94.2037	-.381	94.2750	-.110	94.3462	-.189
92.1849	-.324	92.2563	-.391	92.3277	-.015	92.3990	-.281	94.2047	-.388	94.2760	-.114	94.3472	-.199
92.1859	-.323	92.2573	-.383	92.3287	-.002	92.4000	-.286	94.2057	-.386	94.2770	-.105	94.3482	-.194
92.1869	-.320	92.2583	-.376	92.3296	.006	92.4010	-.286	94.2067	-.375	94.2780	-.095	94.3492	-.204
92.1879	-.337	92.2593	-.374	92.3306	.012	92.4020	-.290	94.2077	-.373	94.2789	-.080	94.3502	-.227
92.1889	-.325	92.2603	-.376	92.3316	.001	92.4030	-.292	94.2087	-.375	94.2799	-.073	94.3512	-.220
92.1899	-.328	92.2613	-.368	92.3326	.009	92.4040	-.302	94.2097	-.374	94.2809	-.079	94.3522	-.215
92.1909	-.343	92.2623	-.365	92.3336	.004	92.4050	-.309	94.2107	-.374	94.2819	-.069	94.3531	-.219
92.1919	-.330	92.2632	-.369	92.3346	.003	92.4060	-.308	94.2117	-.368	94.2829	-.058	94.3541	-.234
92.1929	-.336	92.2642	-.362	92.3356	.003	92.4070	-.314	94.2126	-.370	94.2839	-.066	94.3551	-.243
92.1939	-.341	92.2652	-.354	92.3366	.002	92.4079	-.313	94.2136	-.363	94.2849	-.054	94.3561	-.240
92.1949	-.345	92.2662	-.346	92.3376	.019	92.4089	-.313	94.2146	-.358	94.2859	-.051	94.3571	-.242
92.1958	-.343	92.2672	-.349	92.3386	.011	92.4099	-.329	94.2156	-.370	94.2869	-.043	94.3581	-.258
92.1968	-.346	92.2682	-.357	92.3396	.019	92.4109	-.324	94.2166	-.371	94.2878	-.056	94.3591	-.263
92.1978	-.357	92.2692	-.339	92.3405	.009	92.4119	-.334	94.2176	-.373	94.2888	-.054	94.3601	-.267
92.1988	-.357	92.2702	-.344	92.3415	.012	92.4129	-.342	94.2186	-.362	94.2898	-.058	94.3611	-.279
92.1998	-.365	92.2712	-.333	92.3425	.012	92.4139	-.332	94.2196	-.356	94.2908	-.052	94.3621	-.279
92.2008	-.366	92.2722	-.323	92.3435	.008	92.4149	-.348	94.2206	-.354	94.2918	-.046	94.3631	-.280
92.2018	-.369	92.2731	-.326	92.3445	.003	92.4159	-.348	94.2216	-.349	94.2928	-.053	94.3640	-.286
92.2028	-.371	92.2741	-.317	92.3455	.008	92.4169	-.369	94.2225	-.357	94.2938	-.052	94.3650	-.290
92.2038	-.382	92.2751	-.318	92.3465	.015	92.4179	-.346	94.2235	-.341	94.2948	-.052	94.3660	-.291
92.2048	-.370	92.2761	-.310	92.3475	.012	92.4188	-.348	94.2245	-.337	94.2958	-.053	94.3670	-.301
92.2058	-.389	92.2771	-.310	92.3485	.003	92.4198	-.375	94.2255	-.351	94.2968	-.042	94.3680	-.306
92.2067	-.377	92.2781	-.309	92.3495	.007	92.4208	-.338	94.2265	-.336	94.2978	-.050	94.3690	-.292
92.2077	-.380	92.2791	-.290	92.3505	.011	92.4218	-.359	94.2275	-.341	94.2987	-.041	94.3700	-.316
92.2087	-.387	92.2801	-.300	92.3514	.000	92.4228	-.371	94.2285	-.335	94.2997	-.048	94.3710	-.302
92.2097	-.392	92.2811	-.286	92.3524	-.004	92.4238	-.347	94.2295	-.329	94.3007	-.046	94.3720	-.314
92.2107	-.396	92.2821	-.289	92.3534	-.007	92.4248	-.369	94.2305	-.324	94.3017	-.055	94.3730	-.303
92.2117	-.389	92.2831	-.272	92.3544	-.005	92.4258	-.368	94.2314	-.327	94.3027	-.049	94.3739	-.311
92.2127	-.405	92.2841	-.271	92.3554	-.002	92.4268	-.365	94.2324	-.327	94.3037	-.044	94.3749	-.315
92.2137	-.408	92.2850	-.267	92.3564	-.003	92.4278	-.393	94.2334	-.315	94.3047	-.044	94.3759	-.334
92.2147	-.398	92.2860	-.263	92.3574	-.008	92.4288	-.406	94.2344	-.298	94.3057	-.057	94.3769	-.316
92.2157	-.393	92.2870	-.249	92.3584	-.008	92.4297	-.413	94.2354	-.298	94.3067	-.046	94.3779	-.314
92.2167	-.403	92.2880	-.252	92.3594	-.010	92.4307	-.441	94.2364	-.310	94.3077	-.046	94.3789	-.331
92.2177	-.409	92.2890	-.242	92.3604	-.017	92.4317	-.391	94.2374	-.302	94.3086	-.053	94.3799	-.325
92.2186	-.409	92.2900	-.244	92.3614	-.027	92.4327	-.405	94.2384	-.293	94.3096	-.047	94.3809	-.330
92.2196	-.401	92.2910	-.222	92.3624	-.034	92.4337	-.433	94.2394	-.300	94.3106	-.056	96.1046	-.253
92.2206	-.405	92.2920	-.228	92.3633	-.035	92.4347	-.401	94.2404	-.291	94.3116	-.055	96.1056	-.258
92.2216	-.412	92.2930	-.215	92.3643	-.041	92.4357	-.405	94.2414	-.290	94.3126	-.046	96.1066	-.266
92.2226	-.414	92.2940	-.212	92.3653	-.049	92.4367	-.396	94.2423	-.285	94.3136	-.058	96.1076	-.271
92.2236	-.415	92.2950	-.201	92.3663	-.050	92.4377	-.383	94.2433	-.294	94.3146	-.045	96.1086	-.279
92.2246	-.410	92.2960	-.209	92.3673	-.061	92.4387	-.388	94.2443	-.282	94.3156	-.052	96.1096	-.280
92.2256	-.413	92.2969	-.191	92.3683	-.080	92.4397	-.402	94.2453	-.281	94.3166	-.060	96.1106	-.278
92.2266	-.407	92.2979	-.185	92.3693	-.084	92.4406	-.422	94.2463	-.270	94.3175	-.055	96.1116	-.285
92.2276	-.409	92.2989	-.176	92.3703	-.090	92.4416	-.324	94.2473	-.277	94.3185	-.037	96.1126	-.287
92.2286	-.410	92.2999	-.165	92.3713	-.091	94.1770	-.371	94.2483	-.275	94.3195	-.061	96.1135	-.283
92.2295	-.417	92.3009	-.162	92.3723	-.106	94.1780	-.366	94.2493	-.262	94.3205	-.042	96.1145	-.300
92.2305	-.420	92.3019	-.149	92.3733	-.113	94.1790	-.376	94.2503	-.259	94.3215	-.057	96.1155	-.298
92.2315	-.415	92.3029	-.153	92.3742	-.124	94.1800	-.375	94.2513	-.255	94.3225	-.067	96.1165	-.302
92.2325	-.416	92.3039	-.142	92.3752	-.138	94.1810	-.384	94.2522	-.239	94.3235	-.048	96.1175	-.309
92.2335	-.416	92.3049	-.129	92.3762	-.137	94.1820	-.382	94.2532	-.252	94.3245	-.057	96.1185	-.304
92.2345	-.418	92.3059	-.125	92.3772	-.136	94.1830	-.384	94.2542	-.244	94.3255	-.040	96.1195	-.319
92.2355	-.409	92.3069	-.115	92.3782	-.145	94.1840	-.383	94.2552	-.226	94.3264	-.045	96.1205	-.315
92.2365	-.421	92.3078	-.109	92.3792	-.152	94.1850	-.397	94.2562	-.227	94.3274	-.058	96.1215	-.334
92.2375	-.416	92.3088	-.104	92.3802	-.166	94.1859	-.392	94.2572	-.231	94.3284	-.068	96.1225	-.333
92.2385	-.406	92.3098	-.097	92.3812	-.176	94.1869	-.385	94.2582	-.216	94.3294	-.075	96.1234	-.330
92.2395	-.420	92.3108	-.083	92.3822	-.176	94.1879	-.388	94.2592	-.218	94.3304	-.078	96.1244	-.329
92.2405	-.412	92.3118	-.077	92.3832	-.179	94.1889	-.387	94.2602	-.214	94.3314	-.084	96.1254	-.336
92.2414	-.410	92.3128	-.075	92.3842	-.198	94.1899	-.392	94.2611	-.211	94.3324	-.089	96.1264	-.332
92.2424	-.401	92.3138	-.065	92.3852	-.201	94.1909	-.392	94.2621	-.203	94.3334	-.067	96.1274	-.345
92.2434	-.400	92.3148	-.070	92.3861	-.200	94.1919	-.392	94.2631	-.189	94.3344	-.103	96.1284	-.343
92.2444	-.418	92.3158	-.053	92.3871	-.209	94.1929	-.388	94.2641	-.191	94.3353	-.104	96.1294	-.350
92.2454	-.412	92.3168	-.038	92.3881	-.206	94.1939	-.392	94.2651	-.184	94.3363	-.099	96.1304	-.354
92.2464	-.401	92.3178	-.037	92.3891	-.214	94.1948	-.394	94.2661	-.172	94.3373	-.129	96.1314	-.356
92.2474	-.402	92.3188	-.033	92.3901	-.230	94.1958	-.388	94.2671	-.158	94.3383	-.119	96.1324	-.349
92.2484	-.393	92.3197	-.020	92.3911	-.222	94.1968	-.384	94.2681	-.166	94.3393	-.128	96.1334	-.357
92.2494	-.396	92.3207	-.019	92.3921	-.236	94.1978	-.393	94.2691	-.153	94.3403	-.130	96.1343	-.361
92.2504	-.402	92.3217	-.007	92.3931	-.245	94.1988	-.391	94.2700	-.150	94.3413	-.154	96.1353	-.367
92.2514	-.398	92.3227	-.008	92.3941	-.252	94.1998	-.387	94.2710	-.141	94.3423	-.155	96.1363	-.374
92.2523	-.392	92.3237	.002	92.3951	-.254	94.2008	-.388	94.2720	-.132	94.3433	-.163	96.1373	-.363
92.2533	-.391	92.3247	-.011	92.3961	-.268	94.2018	-.398	94.2730	-.131	94.3443	-.175	96.1383	-.372

Table 3: The original photometric data (HJD-2454400) of XY LMi in V band.

HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm
92.1827	-.381	92.2546	-.438	92.3260	-.068	92.3973	-.329	94.2030	-.453	94.2743	-.184	94.3455	-.245
92.1842	-.371	92.2556	-.434	92.3269	-.071	92.3983	-.357	94.2040	-.445	94.2753	-.176	94.3465	-.251
92.1852	-.365	92.2566	-.438	92.3279	-.074	92.3993	-.348	94.2050	-.452	94.2763	-.177	94.3475	-.257
92.1862	-.382	92.2576	-.435	92.3289	-.073	92.4003	-.345	94.2060	-.437	94.2772	-.174	94.3485	-.265
92.1872	-.385	92.2586	-.428	92.3299	-.062	92.4013	-.359	94.2070	-.452	94.2782	-.162	94.3495	-.269
92.1882	-.390	92.2595	-.442	92.3309	-.064	92.4023	-.344	94.2080	-.439	94.2792	-.160	94.3505	-.273
92.1892	-.397	92.2605	-.424	92.3319	-.072	92.4033	-.362	94.2089	-.443	94.2802	-.150	94.3514	-.275
92.1902	-.384	92.2615	-.427	92.3329	-.071	92.4042	-.350	94.2099	-.438	94.2812	-.143	94.3524	-.281
92.1912	-.396	92.2625	-.451	92.3339	-.073	92.4052	-.367	94.2109	-.430	94.2822	-.138	94.3534	-.295
92.1922	-.395	92.2635	-.423	92.3349	-.073	92.4062	-.364	94.2119	-.438	94.2832	-.121	94.3544	-.296
92.1931	-.398	92.2645	-.417	92.3359	-.071	92.4072	-.390	94.2129	-.413	94.2842	-.132	94.3554	-.297
92.1941	-.394	92.2655	-.415	92.3369	-.068	92.4082	-.382	94.2139	-.433	94.2851	-.112	94.3564	-.313
92.1951	-.407	92.2665	-.414	92.3378	-.071	92.4092	-.382	94.2149	-.430	94.2861	-.111	94.3574	-.319
92.1961	-.415	92.2675	-.402	92.3388	-.070	92.4102	-.392	94.2159	-.438	94.2871	-.113	94.3584	-.315
92.1971	-.414	92.2685	-.404	92.3398	-.067	92.4112	-.380	94.2169	-.419	94.2881	-.127	94.3594	-.329
92.1981	-.410	92.2695	-.401	92.3408	-.071	92.4122	-.418	94.2179	-.425	94.2891	-.117	94.3603	-.333
92.1991	-.410	92.2704	-.395	92.3418	-.058	92.4132	-.401	94.2188	-.428	94.2901	-.116	94.3613	-.338
92.2001	-.421	92.2714	-.396	92.3428	-.068	92.4142	-.397	94.2198	-.422	94.2911	-.109	94.3623	-.340
92.2011	-.423	92.2724	-.391	92.3438	-.073	92.4151	-.396	94.2208	-.416	94.2921	-.119	94.3633	-.337
92.2021	-.432	92.2734	-.380	92.3448	-.067	92.4161	-.403	94.2218	-.412	94.2931	-.115	94.3643	-.348
92.2031	-.433	92.2744	-.386	92.3458	-.068	92.4171	-.435	94.2228	-.410	94.2941	-.125	94.3653	-.343
92.2040	-.427	92.2754	-.378	92.3468	-.079	92.4181	-.422	94.2238	-.410	94.2950	-.110	94.3663	-.367
92.2050	-.431	92.2764	-.368	92.3478	-.069	92.4191	-.428	94.2248	-.402	94.2960	-.112	94.3673	-.338
92.2060	-.437	92.2774	-.367	92.3487	-.075	92.4201	-.414	94.2258	-.404	94.2970	-.107	94.3683	-.359
92.2070	-.439	92.2784	-.361	92.3497	-.081	92.4211	-.410	94.2268	-.403	94.2980	-.116	94.3692	-.359
92.2080	-.450	92.2794	-.358	92.3507	-.070	92.4221	-.408	94.2277	-.399	94.2990	-.123	94.3702	-.363
92.2090	-.446	92.2804	-.347	92.3517	-.074	92.4231	-.419	94.2287	-.389	94.3000	-.107	94.3712	-.366
92.2100	-.447	92.2813	-.358	92.3527	-.077	92.4241	-.426	94.2297	-.383	94.3010	-.088	94.3722	-.369
92.2110	-.446	92.2823	-.348	92.3537	-.080	92.4251	-.427	94.2307	-.387	94.3020	-.106	94.3732	-.370
92.2120	-.450	92.2833	-.337	92.3547	-.079	92.4260	-.446	94.2317	-.399	94.3030	-.099	94.3742	-.370
92.2130	-.456	92.2843	-.338	92.3557	-.078	92.4270	-.441	94.2327	-.381	94.3039	-.105	94.3752	-.409
92.2139	-.455	92.2853	-.327	92.3567	-.082	92.4280	-.487	94.2337	-.399	94.3049	-.108	94.3762	-.359
92.2149	-.459	92.2863	-.315	92.3577	-.080	92.4290	-.431	94.2347	-.374	94.3059	-.112	94.3772	-.387
92.2159	-.451	92.2873	-.307	92.3586	-.094	92.4300	-.467	94.2357	-.382	94.3069	-.106	94.3782	-.379
92.2169	-.463	92.2883	-.317	92.3596	-.077	92.4310	-.410	94.2367	-.377	94.3079	-.123	94.3792	-.402
92.2179	-.453	92.2893	-.313	92.3606	-.094	92.4320	-.440	94.2377	-.378	94.3089	-.104	94.3801	-.374
92.2189	-.463	92.2903	-.307	92.3616	-.099	92.4330	-.465	94.2386	-.362	94.3099	-.102	94.3811	-.428
92.2199	-.468	92.2913	-.288	92.3626	-.091	92.4340	-.391	94.2396	-.368	94.3109	-.114	96.1049	-.307
92.2209	-.455	92.2922	-.290	92.3636	-.103	92.4350	-.471	94.2406	-.374	94.3119	-.115	96.1059	-.316
92.2219	-.463	92.2932	-.289	92.3646	-.110	92.4360	-.466	94.2416	-.344	94.3129	-.113	96.1069	-.321
92.2229	-.458	92.2942	-.276	92.3656	-.118	92.4369	-.427	94.2426	-.348	94.3138	-.105	96.1079	-.317
92.2239	-.467	92.2952	-.273	92.3666	-.136	92.4379	-.425	94.2436	-.357	94.3148	-.118	96.1088	-.339
92.2249	-.469	92.2962	-.255	92.3676	-.138	92.4389	-.450	94.2446	-.352	94.3158	-.117	96.1098	-.334
92.2258	-.459	92.2972	-.264	92.3686	-.137	92.4399	-.517	94.2456	-.345	94.3168	-.127	96.1108	-.347
92.2268	-.467	92.2982	-.238	92.3695	-.146	92.4409	-.370	94.2466	-.335	94.3178	-.123	96.1118	-.352
92.2278	-.468	92.2992	-.243	92.3705	-.172	92.4419	-.467	94.2475	-.350	94.3188	-.118	96.1128	-.354
92.2288	-.467	92.3002	-.229	92.3715	-.173	94.1773	-.435	94.2485	-.331	94.3198	-.113	96.1138	-.339
92.2298	-.477	92.3012	-.228	92.3725	-.180	94.1783	-.424	94.2495	-.336	94.3208	-.120	96.1148	-.360
92.2308	-.477	92.3022	-.223	92.3735	-.178	94.1793	-.433	94.2505	-.317	94.3218	-.117	96.1158	-.357
92.2318	-.465	92.3031	-.218	92.3745	-.192	94.1803	-.434	94.2515	-.313	94.3227	-.118	96.1168	-.372
92.2328	-.464	92.3041	-.200	92.3755	-.199	94.1813	-.452	94.2525	-.321	94.3237	-.107	96.1178	-.366
92.2338	-.462	92.3051	-.206	92.3765	-.195	94.1822	-.445	94.2535	-.309	94.3247	-.122	96.1188	-.364
92.2348	-.457	92.3061	-.199	92.3775	-.194	94.1832	-.431	94.2545	-.308	94.3257	-.117	96.1197	-.375
92.2358	-.476	92.3071	-.187	92.3785	-.217	94.1842	-.444	94.2555	-.293	94.3267	-.124	96.1207	-.376
92.2367	-.473	92.3081	-.187	92.3795	-.220	94.1852	-.435	94.2565	-.290	94.3277	-.131	96.1217	-.381
92.2377	-.475	92.3091	-.166	92.3805	-.218	94.1862	-.442	94.2574	-.286	94.3287	-.139	96.1227	-.375
92.2387	-.464	92.3101	-.154	92.3814	-.242	94.1872	-.453	94.2584	-.286	94.3297	-.146	96.1237	-.394
92.2397	-.472	92.3111	-.154	92.3824	-.247	94.1882	-.452	94.2594	-.278	94.3307	-.136	96.1247	-.393
92.2407	-.469	92.3121	-.143	92.3834	-.224	94.1892	-.450	94.2604	-.269	94.3317	-.136	96.1257	-.391
92.2417	-.465	92.3131	-.132	92.3844	-.268	94.1902	-.451	94.2614	-.248	94.3326	-.154	96.1267	-.398
92.2427	-.460	92.3141	-.122	92.3854	-.266	94.1912	-.450	94.2624	-.260	94.3336	-.152	96.1277	-.401
92.2437	-.463	92.3150	-.131	92.3864	-.264	94.1921	-.457	94.2634	-.256	94.3346	-.162	96.1287	-.405
92.2447	-.465	92.3160	-.116	92.3874	-.276	94.1931	-.445	94.2644	-.249	94.3356	-.183	96.1297	-.410
92.2457	-.467	92.3170	-.112	92.3884	-.282	94.1941	-.453	94.2654	-.254	94.3366	-.180	96.1307	-.408
92.2467	-.466	92.3180	-.103	92.3894	-.287	94.1951	-.451	94.2664	-.236	94.3376	-.186	96.1316	-.419
92.2477	-.457	92.3190	-.094	92.3904	-.281	94.1961	-.437	94.2673	-.238	94.3386	-.189	96.1326	-.418
92.2486	-.457	92.3200	-.099	92.3914	-.310	94.1971	-.443	94.2683	-.223	94.3396	-.187	96.1336	-.422
92.2496	-.454	92.3210	-.088	92.3924	-.307	94.1981	-.439	94.2693	-.207	94.3406	-.202	96.1346	-.417
92.2506	-.457	92.3220	-.088	92.3933	-.313	94.1991	-.443	94.2703	-.212	94.3416	-.205	96.1356	-.422
92.2516	-.460	92.3230	-.088	92.3943	-.321	94.2000	-.442	94.2713	-.215	94.3425	-.213	96.1366	-.432
92.2526	-.450	92.3240	-.086	92.3953	-.316	94.2010	-.442	94.2723	-.198	94.3435	-.219	96.1376	-.425
92.2536	-.443	92.3250	-.081	92.3963	-.322	94.2020	-.445	94.2733	-.198	94.3445	-.227	96.1386	-.422

Table 4: The original photometric data (HJD-2454400) of XY LMi in R band.

HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm
92.1830	-.395	92.2548	-.477	92.3262	-.116	92.3975	-.381	94.2072	-.469	94.2784	-.191	94.3497	-.317
92.1844	-.407	92.2558	-.478	92.3272	-.125	92.3985	-.373	94.2082	-.485	94.2794	-.184	94.3507	-.313
92.1854	-.414	92.2568	-.464	92.3282	-.122	92.3995	-.396	94.2092	-.470	94.2804	-.180	94.3517	-.309
92.1864	-.405	92.2578	-.468	92.3291	-.111	92.4005	-.385	94.2102	-.463	94.2814	-.175	94.3527	-.325
92.1874	-.404	92.2588	-.458	92.3301	-.130	92.4015	-.370	94.2112	-.475	94.2824	-.167	94.3536	-.324
92.1884	-.417	92.2598	-.457	92.3311	-.120	92.4025	-.387	94.2121	-.468	94.2834	-.159	94.3546	-.333
92.1894	-.404	92.2608	-.458	92.3321	-.123	92.4035	-.387	94.2131	-.464	94.2844	-.162	94.3556	-.337
92.1904	-.424	92.2617	-.452	92.3331	-.107	92.4045	-.398	94.2141	-.463	94.2854	-.154	94.3566	-.340
92.1914	-.427	92.2627	-.454	92.3341	-.131	92.4055	-.396	94.2151	-.454	94.2864	-.142	94.3576	-.342
92.1924	-.417	92.2637	-.449	92.3351	-.102	92.4065	-.406	94.2161	-.463	94.2873	-.146	94.3586	-.344
92.1934	-.436	92.2647	-.440	92.3361	-.112	92.4074	-.410	94.2171	-.447	94.2883	-.149	94.3596	-.350
92.1944	-.427	92.2657	-.436	92.3371	-.128	92.4084	-.421	94.2181	-.456	94.2893	-.155	94.3606	-.360
92.1953	-.439	92.2667	-.430	92.3381	-.118	92.4094	-.413	94.2191	-.443	94.2903	-.155	94.3616	-.359
92.1963	-.438	92.2677	-.439	92.3391	-.113	92.4104	-.407	94.2201	-.451	94.2913	-.157	94.3626	-.371
92.1973	-.440	92.2687	-.434	92.3400	-.107	92.4114	-.426	94.2211	-.455	94.2923	-.146	94.3635	-.369
92.1983	-.450	92.2697	-.432	92.3410	-.112	92.4124	-.422	94.2220	-.449	94.2933	-.154	94.3645	-.371
92.1993	-.438	92.2707	-.418	92.3420	-.101	92.4134	-.419	94.2230	-.432	94.2943	-.140	94.3655	-.382
92.2003	-.450	92.2717	-.422	92.3430	-.122	92.4144	-.306	94.2240	-.444	94.2953	-.146	94.3665	-.364
92.2013	-.459	92.2727	-.407	92.3440	-.124	92.4154	-.466	94.2250	-.441	94.2963	-.138	94.3675	-.378
92.2023	-.456	92.2736	-.413	92.3450	-.127	92.4164	-.447	94.2260	-.437	94.2973	-.148	94.3685	-.394
92.2033	-.465	92.2746	-.417	92.3460	-.105	92.4174	-.423	94.2270	-.432	94.2982	-.138	94.3695	-.403
92.2043	-.468	92.2756	-.404	92.3470	-.133	92.4183	-.434	94.2280	-.436	94.2992	-.147	94.3705	-.392
92.2053	-.480	92.2766	-.405	92.3480	-.111	92.4193	-.450	94.2290	-.426	94.3002	-.130	94.3715	-.404
92.2063	-.478	92.2776	-.393	92.3490	-.107	92.4203	-.451	94.2300	-.422	94.3012	-.141	94.3725	-.409
92.2072	-.472	92.2786	-.393	92.3500	-.106	92.4213	-.434	94.2309	-.431	94.3022	-.153	94.3734	-.389
92.2082	-.465	92.2796	-.382	92.3510	-.121	92.4223	-.471	94.2319	-.409	94.3032	-.136	94.3744	-.420
92.2092	-.475	92.2806	-.395	92.3519	-.111	92.4233	-.435	94.2329	-.453	94.3042	-.149	94.3754	-.413
92.2102	-.482	92.2816	-.381	92.3529	-.117	92.4243	-.473	94.2339	-.404	94.3052	-.134	94.3764	-.396
92.2112	-.483	92.2826	-.374	92.3539	-.103	92.4253	-.461	94.2349	-.419	94.3062	-.142	94.3774	-.422
92.2122	-.480	92.2836	-.365	92.3549	-.123	92.4263	-.454	94.2359	-.403	94.3072	-.143	94.3784	-.375
92.2132	-.482	92.2845	-.361	92.3559	-.130	92.4273	-.434	94.2369	-.421	94.3081	-.139	94.3794	-.439
92.2142	-.481	92.2855	-.368	92.3569	-.116	92.4283	-.512	94.2379	-.395	94.3091	-.145	94.3804	-.426
92.2152	-.478	92.2865	-.364	92.3579	-.126	92.4292	-.434	94.2389	-.403	94.3101	-.152	94.3814	-.424
92.2162	-.495	92.2875	-.351	92.3589	-.123	92.4302	-.497	94.2399	-.401	94.3111	-.166	96.1051	-.346
92.2172	-.491	92.2885	-.340	92.3599	-.129	92.4312	-.465	94.2409	-.380	94.3121	-.147	96.1061	-.347
92.2181	-.488	92.2895	-.347	92.3609	-.125	92.4322	-.471	94.2418	-.385	94.3131	-.141	96.1071	-.347
92.2191	-.478	92.2905	-.337	92.3619	-.138	92.4332	-.492	94.2428	-.386	94.3141	-.146	96.1081	-.342
92.2201	-.506	92.2915	-.330	92.3628	-.144	92.4352	-.500	94.2438	-.373	94.3151	-.152	96.1091	-.369
92.2211	-.491	92.2925	-.320	92.3638	-.144	92.4362	-.476	94.2448	-.376	94.3161	-.147	96.1101	-.358
92.2221	-.509	92.2935	-.319	92.3648	-.168	92.4372	-.475	94.2458	-.370	94.3170	-.141	96.1111	-.367
92.2231	-.501	92.2945	-.297	92.3658	-.172	92.4392	-.497	94.2468	-.376	94.3180	-.138	96.1120	-.378
92.2241	-.498	92.2955	-.300	92.3668	-.178	92.4421	-.463	94.2478	-.365	94.3190	-.153	96.1130	-.373
92.2251	-.491	92.2964	-.304	92.3678	-.185	94.1775	-.462	94.2488	-.362	94.3200	-.144	96.1140	-.384
92.2261	-.500	92.2974	-.295	92.3688	-.184	94.1785	-.462	94.2498	-.363	94.3210	-.146	96.1150	-.387
92.2271	-.506	92.2984	-.269	92.3698	-.194	94.1795	-.469	94.2508	-.362	94.3220	-.141	96.1160	-.392
92.2281	-.500	92.2994	-.289	92.3708	-.200	94.1805	-.455	94.2517	-.360	94.3230	-.150	96.1170	-.379
92.2291	-.496	92.3004	-.287	92.3718	-.182	94.1815	-.472	94.2527	-.338	94.3240	-.143	96.1180	-.398
92.2300	-.516	92.3014	-.264	92.3728	-.222	94.1825	-.475	94.2537	-.335	94.3250	-.144	96.1190	-.404
92.2310	-.496	92.3024	-.257	92.3738	-.222	94.1835	-.472	94.2547	-.331	94.3259	-.159	96.1200	-.416
92.2320	-.505	92.3034	-.254	92.3747	-.229	94.1845	-.484	94.2557	-.338	94.3269	-.158	96.1210	-.404
92.2330	-.502	92.3044	-.236	92.3757	-.226	94.1855	-.480	94.2567	-.327	94.3279	-.147	96.1220	-.397
92.2340	-.503	92.3054	-.232	92.3767	-.261	94.1864	-.470	94.2577	-.324	94.3289	-.164	96.1229	-.407
92.2350	-.499	92.3064	-.224	92.3777	-.261	94.1874	-.466	94.2587	-.315	94.3299	-.162	96.1239	-.421
92.2360	-.498	92.3074	-.217	92.3787	-.238	94.1884	-.481	94.2597	-.314	94.3309	-.163	96.1249	-.422
92.2370	-.509	92.3083	-.216	92.3797	-.256	94.1894	-.483	94.2606	-.317	94.3319	-.178	96.1259	-.431
92.2380	-.498	92.3093	-.206	92.3807	-.270	94.1904	-.473	94.2616	-.304	94.3329	-.168	96.1269	-.422
92.2390	-.482	92.3103	-.197	92.3817	-.257	94.1914	-.482	94.2626	-.299	94.3339	-.196	96.1279	-.429
92.2400	-.493	92.3113	-.199	92.3827	-.274	94.1924	-.472	94.2636	-.285	94.3348	-.205	96.1289	-.435
92.2409	-.488	92.3123	-.189	92.3837	-.284	94.1934	-.466	94.2646	-.284	94.3358	-.198	96.1299	-.441
92.2419	-.503	92.3133	-.180	92.3847	-.309	94.1944	-.474	94.2656	-.281	94.3368	-.210	96.1309	-.435
92.2429	-.488	92.3143	-.172	92.3856	-.295	94.1953	-.483	94.2666	-.275	94.3378	-.200	96.1319	-.442
92.2439	-.482	92.3153	-.158	92.3866	-.294	94.1963	-.469	94.2676	-.266	94.3388	-.231	96.1329	-.452
92.2449	-.489	92.3163	-.165	92.3876	-.313	94.1973	-.467	94.2686	-.263	94.3398	-.227	96.1338	-.449
92.2459	-.482	92.3173	-.152	92.3886	-.312	94.1983	-.482	94.2695	-.252	94.3408	-.241	96.1348	-.462
92.2469	-.479	92.3182	-.153	92.3896	-.305	94.1993	-.489	94.2705	-.244	94.3418	-.244	96.1358	-.457
92.2479	-.492	92.3192	-.140	92.3906	-.320	94.2003	-.477	94.2715	-.236	94.3428	-.248	96.1368	-.458
92.2489	-.496	92.3202	-.124	92.3916	-.324	94.2013	-.475	94.2725	-.234	94.3438	-.260	96.1378	-.461
92.2499	-.460	92.3212	-.134	92.3926	-.327	94.2023	-.471	94.2735	-.218	94.3447	-.277		
92.2509	-.481	92.3222	-.121	92.3936	-.342	94.2032	-.483	94.2745	-.206	94.3457	-.280		
92.2518	-.478	92.3232	-.135	92.3946	-.346	94.2042	-.478	94.2755	-.208	94.3467	-.281		
92.2528	-.474	92.3242	-.110	92.3956	-.367	94.2052	-.462	94.2765	-.198	94.3477	-.274		
92.2538	-.471	92.3252	-.121	92.3965	-.368	94.2062	-.475	94.2775	-.199	94.3487	-.294		

Table 5: The original photometric data (HJD-2454400) of XY LMi in I band.

HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm	HJD	Δm
92.1832	-.416	92.2550	-.477	92.3264	-.153	92.3978	-.404	94.2035	-.483	94.2747	-.230	94.3459	-.285
92.1847	-.435	92.2560	-.485	92.3274	-.131	92.3987	-.370	94.2044	-.484	94.2757	-.224	94.3469	-.298
92.1856	-.416	92.2570	-.484	92.3284	-.144	92.3997	-.383	94.2054	-.483	94.2767	-.222	94.3479	-.303
92.1866	-.421	92.2580	-.481	92.3294	-.149	92.4007	-.466	94.2064	-.479	94.2777	-.211	94.3489	-.309
92.1876	-.434	92.2590	-.475	92.3304	-.139	92.4017	-.380	94.2074	-.492	94.2787	-.217	94.3499	-.309
92.1886	-.439	92.2600	-.478	92.3313	-.152	92.4027	-.486	94.2084	-.489	94.2797	-.208	94.3509	-.329
92.1896	-.429	92.2610	-.470	92.3323	-.146	92.4037	-.419	94.2094	-.485	94.2806	-.190	94.3519	-.337
92.1906	-.444	92.2620	-.468	92.3333	-.142	92.4047	-.491	94.2104	-.480	94.2816	-.181	94.3529	-.324
92.1916	-.435	92.2630	-.464	92.3343	-.139	92.4057	-.550	94.2114	-.482	94.2826	-.189	94.3539	-.344
92.1926	-.442	92.2640	-.463	92.3353	-.149	92.4067	-.417	94.2124	-.481	94.2836	-.182	94.3548	-.339
92.1936	-.452	92.2649	-.454	92.3363	-.131	92.4077	-.423	94.2134	-.485	94.2846	-.162	94.3558	-.349
92.1946	-.448	92.2659	-.455	92.3373	-.135	92.4087	-.425	94.2143	-.478	94.2856	-.171	94.3568	-.351
92.1956	-.454	92.2669	-.450	92.3383	-.146	92.4096	-.425	94.2153	-.467	94.2866	-.175	94.3578	-.362
92.1966	-.459	92.2679	-.458	92.3393	-.139	92.4106	-.447	94.2163	-.477	94.2876	-.161	94.3588	-.355
92.1975	-.446	92.2689	-.448	92.3403	-.133	92.4116	-.452	94.2173	-.467	94.2886	-.169	94.3598	-.358
92.1985	-.456	92.2699	-.438	92.3413	-.147	92.4126	-.447	94.2183	-.474	94.2895	-.168	94.3608	-.386
92.1995	-.462	92.2709	-.440	92.3422	-.146	92.4136	-.444	94.2193	-.455	94.2905	-.172	94.3618	-.367
92.2005	-.471	92.2719	-.435	92.3432	-.140	92.4146	-.455	94.2203	-.455	94.2915	-.162	94.3628	-.380
92.2015	-.463	92.2729	-.433	92.3442	-.159	92.4156	-.460	94.2213	-.462	94.2925	-.174	94.3638	-.394
92.2025	-.480	92.2739	-.428	92.3452	-.140	92.4166	-.432	94.2223	-.471	94.2935	-.165	94.3647	-.379
92.2035	-.488	92.2749	-.415	92.3462	-.154	92.4176	-.442	94.2233	-.470	94.2945	-.158	94.3657	-.389
92.2045	-.477	92.2758	-.421	92.3472	-.138	92.4186	-.529	94.2242	-.447	94.2955	-.175	94.3667	-.395
92.2055	-.461	92.2768	-.416	92.3482	-.140	92.4196	-.454	94.2252	-.449	94.2965	-.173	94.3677	-.402
92.2065	-.486	92.2778	-.416	92.3492	-.138	92.4205	-.474	94.2262	-.460	94.2975	-.167	94.3687	-.400
92.2075	-.482	92.2788	-.408	92.3502	-.135	92.4215	-.472	94.2272	-.455	94.2985	-.158	94.3697	-.412
92.2085	-.487	92.2798	-.403	92.3512	-.144	92.4225	-.486	94.2282	-.440	94.2994	-.154	94.3707	-.409
92.2094	-.489	92.2808	-.393	92.3522	-.135	92.4235	-.475	94.2292	-.434	94.3004	-.160	94.3717	-.394
92.2104	-.488	92.2818	-.408	92.3531	-.149	92.4245	-.568	94.2302	-.445	94.3014	-.165	94.3727	-.400
92.2114	-.506	92.2828	-.392	92.3541	-.143	92.4255	-.498	94.2312	-.402	94.3024	-.158	94.3737	-.414
92.2124	-.492	92.2838	-.368	92.3551	-.134	92.4265	-.455	94.2322	-.459	94.3034	-.164	94.3747	-.410
92.2134	-.492	92.2848	-.378	92.3561	-.141	92.4275	-.478	94.2331	-.417	94.3044	-.157	94.3756	-.400
92.2144	-.491	92.2858	-.373	92.3571	-.150	92.4285	-.516	94.2341	-.415	94.3054	-.159	94.3766	-.396
92.2154	-.503	92.2867	-.371	92.3581	-.142	92.4295	-.513	94.2351	-.434	94.3064	-.166	94.3776	-.457
92.2164	-.491	92.2877	-.366	92.3591	-.144	92.4305	-.474	94.2361	-.406	94.3074	-.163	94.3786	-.419
92.2174	-.501	92.2887	-.354	92.3601	-.142	92.4314	-.467	94.2371	-.426	94.3084	-.151	94.3796	-.464
92.2184	-.504	92.2897	-.350	92.3611	-.162	92.4324	-.413	94.2381	-.404	94.3093	-.155	94.3806	-.429
92.2194	-.515	92.2907	-.354	92.3621	-.174	92.4334	-.468	94.2391	-.412	94.3103	-.174	94.3816	-.481
92.2203	-.498	92.2917	-.343	92.3631	-.162	92.4344	-.508	94.2401	-.423	94.3113	-.168	96.1053	-.351
92.2213	-.506	92.2927	-.333	92.3641	-.177	92.4354	-.573	94.2411	-.407	94.3123	-.176	96.1063	-.360
92.2223	-.507	92.2937	-.326	92.3650	-.175	92.4364	-.497	94.2421	-.412	94.3133	-.160	96.1073	-.369
92.2233	-.513	92.2947	-.331	92.3660	-.186	92.4374	-.541	94.2431	-.404	94.3143	-.171	96.1083	-.382
92.2243	-.508	92.2957	-.319	92.3670	-.195	92.4384	-.499	94.2440	-.391	94.3153	-.149	96.1093	-.370
92.2253	-.505	92.2967	-.313	92.3680	-.202	92.4394	-.556	94.2450	-.381	94.3163	-.164	96.1103	-.383
92.2263	-.508	92.2977	-.310	92.3690	-.213	92.4404	-.480	94.2460	-.389	94.3173	-.166	96.1113	-.379
92.2273	-.506	92.2986	-.307	92.3700	-.207	92.4414	-.272	94.2470	-.382	94.3183	-.175	96.1123	-.376
92.2283	-.520	92.2996	-.295	92.3710	-.219	92.4424	-.556	94.2480	-.381	94.3192	-.163	96.1133	-.392
92.2293	-.518	92.3006	-.291	92.3720	-.237	94.1777	-.468	94.2490	-.394	94.3202	-.173	96.1143	-.390
92.2303	-.511	92.3016	-.291	92.3730	-.239	94.1787	-.468	94.2500	-.376	94.3212	-.160	96.1152	-.404
92.2313	-.515	92.3026	-.276	92.3740	-.239	94.1797	-.478	94.2510	-.363	94.3222	-.169	96.1162	-.405
92.2322	-.510	92.3036	-.270	92.3750	-.240	94.1807	-.480	94.2520	-.354	94.3232	-.157	96.1172	-.388
92.2332	-.507	92.3046	-.256	92.3760	-.259	94.1817	-.473	94.2529	-.369	94.3242	-.162	96.1182	-.422
92.2342	-.509	92.3056	-.263	92.3769	-.284	94.1827	-.492	94.2539	-.356	94.3252	-.164	96.1192	-.416
92.2352	-.508	92.3066	-.254	92.3779	-.279	94.1837	-.495	94.2549	-.360	94.3262	-.176	96.1202	-.404
92.2362	-.516	92.3076	-.242	92.3789	-.264	94.1847	-.461	94.2559	-.344	94.3272	-.175	96.1212	-.423
92.2372	-.519	92.3086	-.232	92.3799	-.295	94.1857	-.500	94.2569	-.337	94.3281	-.195	96.1222	-.418
92.2382	-.515	92.3095	-.212	92.3809	-.289	94.1867	-.494	94.2579	-.327	94.3291	-.181	96.1232	-.428
92.2392	-.515	92.3105	-.226	92.3819	-.321	94.1876	-.479	94.2589	-.323	94.3301	-.195	96.1242	-.423
92.2402	-.517	92.3115	-.208	92.3829	-.288	94.1886	-.483	94.2599	-.311	94.3311	-.210	96.1251	-.421
92.2412	-.505	92.3125	-.199	92.3839	-.282	94.1896	-.486	94.2609	-.330	94.3321	-.198	96.1261	-.439
92.2422	-.509	92.3135	-.266	92.3849	-.317	94.1906	-.477	94.2619	-.326	94.3331	-.193	96.1271	-.440
92.2431	-.506	92.3145	-.191	92.3859	-.402	94.1916	-.494	94.2628	-.306	94.3341	-.208	96.1281	-.449
92.2441	-.506	92.3155	-.192	92.3869	-.334	94.1926	-.490	94.2638	-.296	94.3351	-.191	96.1291	-.447
92.2451	-.500	92.3165	-.181	92.3878	-.336	94.1936	-.492	94.2648	-.299	94.3361	-.202	96.1301	-.455
92.2461	-.507	92.3175	-.181	92.3888	-.324	94.1946	-.500	94.2658	-.302	94.3370	-.207	96.1311	-.464
92.2471	-.506	92.3185	-.157	92.3898	-.355	94.1956	-.482	94.2668	-.275	94.3380	-.229	96.1321	-.460
92.2481	-.504	92.3195	-.173	92.3908	-.342	94.1965	-.482	94.2678	-.271	94.3390	-.239	96.1331	-.479
92.2491	-.510	92.3205	-.164	92.3918	-.337	94.1975	-.493	94.2688	-.278	94.3400	-.242	96.1341	-.459
92.2501	-.492	92.3214	-.148	92.3928	-.378	94.1985	-.493	94.2698	-.256	94.3410	-.250	96.1351	-.456
92.2511	-.491	92.3224	-.144	92.3938	-.502	94.1995	-.496	94.2708	-.253	94.3420	-.255	96.1360	-.461
92.2521	-.498	92.3234	-.156	92.3948	-.370	94.2005	-.480	94.2717	-.260	94.3430	-.268	96.1370	-.466
92.2531	-.488	92.3244	-.132	92.3958	-.451	94.2015	-.485	94.2727	-.245	94.3440	-.255	96.1380	-.465
92.2540	-.502	92.3254	-.144	92.3968	-.364	94.2025	-.502	94.2737	-.242	94.3450	-.280		

≈ 0.346 mag in I band. As in the light curve obtained by B&B, the eclipses are complete indicating that the BVRI light curves are very useful to determine reliable photometric parameters of the system. Therefore, to derive photometric elements and to understand the evolutionary state of the binary star, the present light curves were analyzed simultaneously with the 2003 version of the W-D program (Wilson & Devinney 1971; Wilson 1979, 1990).

The color indexes of the binary star given by Gettel et al. (2006) and Cutri et al. (2003) are: B-V=0.525; J-H=0.222; H-K=0.049; V-K=1.399, which corresponds different values of temperature for the primary component (Cox, 2000). Therefore, we choose a mean value, i.e., the temperature for star 1 (star eclipsed at primary light minimum) was fixed as $T_1 = 6144$ K. During the analyzing, all of original individual data points were used. We assumed convective outer envelopes for both components, and the bolometric albedo $A_1 = A_2 = 0.5$ (Rucinski 1969) and the values of the gravity-darkening coefficients $g_1 = g_2 = 0.32$ (Lucy 1967) were used. The limb-darkening coefficients for different filters were taken from van Hamme’s table (1993). The adjustable parameters were: the orbital inclination i ; the mean temperature of star 2, T_2 ; the mass ratio $q (q = M_2/M_1)$; the band-pass luminosity of star 1, L_{1B} and L_{1V} ; and the dimensionless potential of star 1 ($\Omega_1 = \Omega_2$, mode 3 for overcontact configuration).

Since no mass ratios of XY LMi are in the previous literature, a q-search method was used to determine its mass ratio. The total and shallow eclipsing minima in the light curves indicate that it is a low mass ratio contact binary with mass ratio between 0.1 and 0.2 (e.g., Wilson, 1978; Terrell & Wilson, 2005; Wilson, 2006). Therefore, we focus on searching for photometric solutions with mass ratio below 0.2, and solutions were carried out for a series of values of the mass ratio ($q=0.13, 0.14, 0.15, 0.16, 0.17, 0.18, 0.19$, and 0.20). For each value of q , the calculation started at mode 2 (detached mode) and we discovered that the solutions usually converged to overcontact configuration. The relation between the resulting sum Σ of weighted square deviations and q is plotted in Fig. 2. A minimum value was obtained at $q=0.16$. Therefore, we chose the initial value of mass ration q as 0.16 and made it an adjustable parameter. Then, we performed a differential correction until it converged and final solutions were derived.

The photometric solutions are listed in Table 6. However, we found that the theoretical light curves do not fit the observations very good between phases 0.65 and 0.80. Both components of the binary are cool stars and shares a common convective envelope. The deep convective envelope along with fast rotation can produce a strong magnetic dynamo and solar-like magnetic activity including photospheric dark spots. Therefore, the disagreement between the theoretical light curve and the observation was explained as the presence of dark spots on the common convective envelope. Two dark spots were introduced , one on each star. In the 2003 version of the W-D program, each spot was described by four parameters:

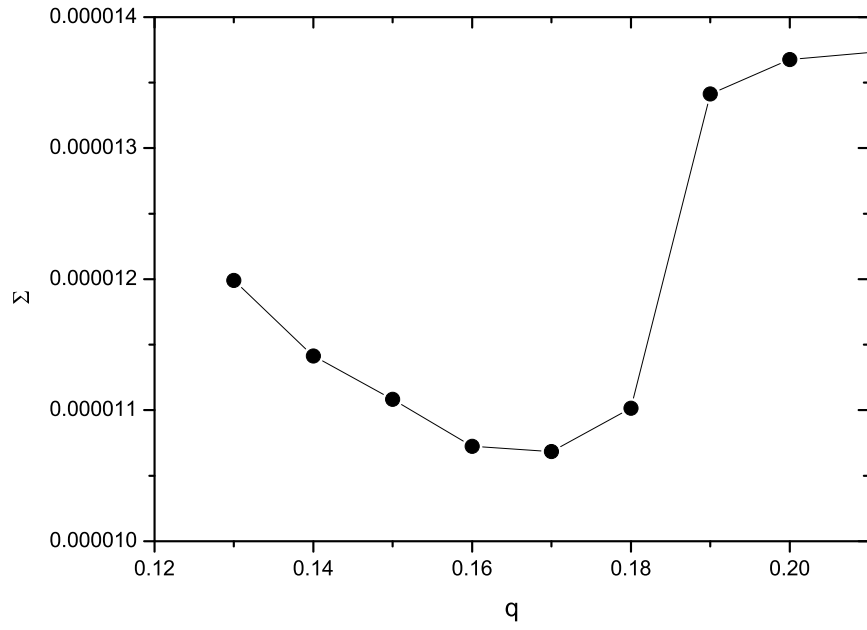


Fig. 2.— The relation between Σ and q for XY Leonis Minoris.

Table 6: Photometric solutions for XY Leonis Minoris.

Parameters	Without spots	With dark spots
$g_1 = g_2$	0.32	0.32
$A_1 = A_2$	0.5	0.5
$x_{1B} = x_{2B}$	0.690	0.690
$x_{1V} = x_{2V}$	0.565	0.565
$x_{1R} = x_{2R}$	0.467	0.467
$x_{1I} = x_{2I}$	0.380	0.380
T_1	6144K	6144K
q	0.1505(± 0.0007)	0.1480(± 0.0008)
Ω_{in}	2.10309	2.09755
Ω_{out}	2.00627	2.00200
T_2	6089(± 6)K	6093(± 6)K
i	81.50(± 0.40)	81.04(± 0.35)
$\Omega_1 = \Omega_2$	2.0268(± 0.0034)	2.0268(± 0.0034)
$L_1/(L_1 + L_2)$ (B)	0.8394(± 0.0002)	0.8390(± 0.0002)
$L_1/(L_1 + L_2)$ (V)	0.8379(± 0.0002)	0.8377(± 0.0001)
$L_1/(L_1 + L_2)$ (R)	0.8371(± 0.0001)	0.8370(± 0.0001)
$L_1/(L_1 + L_2)$ (I)	0.8364(± 0.0001)	0.8363(± 0.0001)
$r_1(pole)$	0.5248(± 0.0010)	0.5275(± 0.0010)
$r_1(side)$	0.5840(± 0.0015)	0.5880(± 0.0015)
$r_1(back)$	0.6101(± 0.0019)	0.6145(± 0.0019)
$r_2(pole)$	0.2350(± 0.0020)	0.2358(± 0.0021)
$r_2(side)$	0.2476(± 0.0025)	0.2488(± 0.0026)
$r_2(back)$	0.3104(± 0.0083)	0.3171(± 0.0098)
The degree of overcontact (f)	66.6(± 3.6 %)	74.1(± 3.6 %)

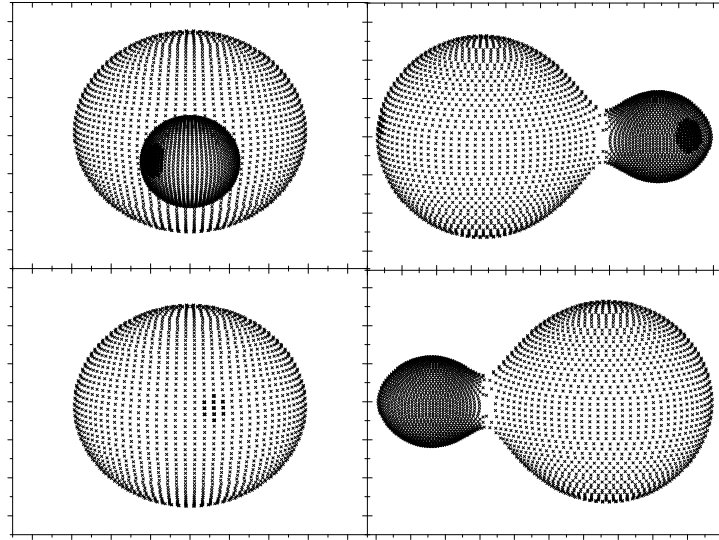


Fig. 3.— Geometrical structure of XY Leonis Minoris with one dark spot on the primary and one on the secondary at phases of 0.00, 0.25, 0.50, and 0.75.

spot center longitude (θ), spot center latitude (ϕ), spot angular radius (r) (all in units of radian), and the spot temperature factor $T_f = T_d/T_0$, the ratio of local spot temperature to unspotted temperature. The photometric solutions with two dark spots are listed in Table 6, and the parameters of the two dark spots are shown in Table 7. The corresponding theoretical light curves are plotted in Fig. 1 that fit the observations better. The geometrical structures of XY LMi at phases of 0.00, 0.25, 0.50, and 0.75, are displayed in Fig. 3. Our photometric solutions suggest that XY LMi is a deep-overcontact binary system with a high degree of overcontact ($f = 74.1\%$). The derived mass ratio is $q = 0.148$.

Recent investigations have shown that nearly 100% of very close binaries ($P < 10$ days), especially W UMa-type binary stars (with the shortest periods among main-sequence binaries of the same spectral types), are members of triple systems (e.g. Tokovinin, et al., 2006; Pribulla & Rucinski, 2006; D’Angelo, et al., 2006; Qian et al., 2006). To check on possible third light, during the solution we also included third light as one of the adjusted parameters. However, the results suggest that third light is negligible and negative indicating that, if there is a third body companion to XY LMi, it should be an extremely faint object.

3. Orbital period variation of XY Leonis Minoris

After the first linear ephemeris of XY LMi derived by B&B, only three eclipse times of the eclipsing binary was obtained by Maciejewski & Karska (2004) and by Hubscher et al. (2009). By using the photometric data published by B&B, 8 times of minimum light were determined and are listed in Table 8. It has shown in previous papers (e.g., Qian & Yang (2004); Zhu et al. (2005); Qian et al. (2005a, b, 2006, 2007, 2008)) that the orbital periods of all of the investigated high fill-out, extreme mass ratio overcontact binaries are variable. To check the orbital period of XY LMi is variable or not, three small telescopes,

Table 7: Parameters of the dark spots on the photospheric surfaces of the two components.

Parameters	Spot 1 (on the primary)	Spot 2 (on the secondary)
$\theta(\text{radian})$	1.4378	1.4377
$\phi(\text{radian})$	3.3554	2.3555
$r(\text{radian})$	0.1247	0.3247
$T_f(T_d/T_0)$	0.8333	0.7033

Note. — Details of explanations on the spot center longitude (θ) and latitude (ϕ) were given by Wilson & Van Hamme (2003).

Table 8: New determined CCD times of light minimum for XY Leonis Minoris

J.D. (Hel.) (days)	Error (days)	Methods	Min.	Filter	Telescopes
2452342.4222	± 0.0022	CCD	I	Non	The 21-cm
2452342.6357	± 0.0005	CCD	II	Non	The 21-cm
2452346.4648	± 0.0006	CCD	II	Non	The 21-cm
2452381.5203	± 0.0006	CCD	II	Non	The 21-cm
2452382.3936	± 0.0009	CCD	II	Non	The 21-cm
2452383.4869	± 0.0004	CCD	I	Non	The 21-cm
2452615.6901	± 0.0009	CCD	II	Non	The 21-cm
2452734.5230	± 0.0010	CCD	II	Non	The 21-cm
2453739.3720	± 0.0015	CCD	II	V	The 60-cm
2453739.3638	± 0.0012	CCD	II	R	The 60-cm
2453766.2260	± 0.0010	CCD	I	B	The 60-cm
2453766.2277	± 0.0011	CCD	I	V	The 60-cm
2453766.2319	± 0.0005	CCD	I	R	The 60-cm
2454492.3408	± 0.0002	CCD	I	B	The 85-cm
2454492.3407	± 0.0002	CCD	I	V	The 85-cm
2454492.3408	± 0.0002	CCD	I	R	The 85-cm
2454492.3409	± 0.0003	CCD	I	I	The 85-cm
2454494.3054	± 0.0003	CCD	II	B	The 85-cm
2454494.3057	± 0.0002	CCD	II	V	The 85-cm
2454494.3062	± 0.0003	CCD	II	R	The 85-cm
2454494.3061	± 0.0002	CCD	II	I	The 85-cm
2454574.0379	± 0.0014	CCD	I	R	The 1.0-m
2454809.3015	± 0.0002	CCD	II	R	The 1.0-m
2454887.2866	± 0.0002	CCD	I	R	The 1.0-m
2454937.0903	± 0.0002	CCD	I	R	The 60-cm
2455296.2123	± 0.0011	CCD	I	R	The 60-cm
2455311.0660	± 0.0006	CCD	I	R	The 60-cm

Note. — Explanations on the used telescopes are as following. The 21-cm: the 21.2-cm telescope in Les Engarouines Observatory; The 60-cm: the 60-cm telescope in Yunnan Astronomical Observatory; The 85-cm: the 85-cm telescope in Xinglong station of National Astronomical Observatories; The 1.0-m: the 1.0-m telescope in Yunnan Astronomical Observatory.

e.g., the 60-cm and the 1.0-m telescopes in Yunnan Astronomical Observatory and the 80-cm telescope in Xinglong station of National Astronomical Observatories, were used to monitor it for determining eclipse times. With our data, 19 times of light minimum were determined by using the parabolic fitting method and are shown in Table 8.

The timing residuals (O-C values) of all available eclipse times were calculated with the linear ephemeris determined by B&B (see in Table 9). The corresponding timing-residual diagram is plotted against epoch number E in Fig. 4. It is shown in the upper panel of Fig. 4 that the B&B period needed refinement (as the plotted relation is not close to horizontal), and the period of XY LMi is variable. By assuming a continuously long-term period change, a least-squares solution leads to the following equation,

$$\begin{aligned} Min.I = & 2452366.88397(\pm 0.00002) + 0.43688773(\pm 0.00000002) \times E \\ & - 1.00(\pm 0.03) \times 10^{-10} \times E^2. \end{aligned} \quad (2)$$

The quadratic term in this equation reveals a period decrease at a rate of $dP/dt = -1.67 \times 10^{-7}$ days/year which is the same order as those determined in other overcontact binaries (e.g., Qian 2001, 2003a, b). After the long-term period change was removed, the residuals respect to the quadratic ephemeris are shown in the lowest panel where no changes can be traced indicating that the quadratic ephemeris can fit timing-residual curve very well.

The continuous period decrease may be caused by angular momentum loss (AML) or by a combination of the mass transfer from the primary to the secondary and angular momentum loss via magnetic stellar wind. As the period is decreasing, the inner and outer critical Roche lobes will be shrinking and thus will cause f increasing. Finally, as in the cases of GR Vir (Qian & Yang, 2004), FG Hya (Qian & Yang, 2005), IK Per (Zhu et al., 2005), CU Tauri, and TV Muscae (Qian et al. 2005a), it will evolve into a single rapid-rotation star before the fluid surface reaching the outer critical Roche Lobe (Rasio & Shapiro 1995). However, the continuous period decrease may be only a part of a long-period cyclic variation or a combination of a cyclic change and a long-term variation as have been observed in other W UMa-type binaries (e.g., V417 Aql, Qian 2003b). Moreover, as shown in Fig. 4, the time interval of eclipse times is only eight years. To check the period change of XY LMi presented here, more times of light minimum are required in the future.

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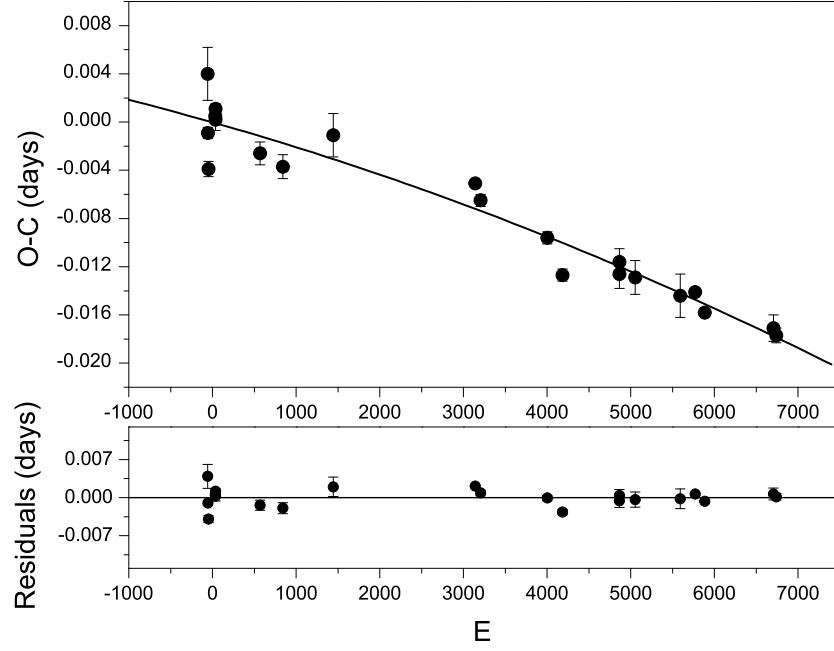


Fig. 4.— $O - C$ diagram of XY Leonis Minoris (upper panel) from the linear ephemeris of Eq. (1). The solid line in the upper panel refers to a continuous period decrease. The residuals respect to the quadratic ephemeris are shown in the lowest panel where no changes can be traced.

Table 9. O-C values of the eclipse times of XY Leonis Minoris.

JD.Hel.	Min.	E	$O - C$	Residuals	Ref.
2400000+					
2452342.4222	I	-56	+0.0040	+0.0039	(1)
2452342.6357	II	-55.5	-0.0009	-0.0010	(1)
2452346.4648	II	-46.5	-0.0039	-0.0040	(1)
2452381.5203	II	33.5	+0.0005	+0.0006	(1)
2452382.3936	II	35.5	+0.0002	+0.0003	(1)
2452383.4869	I	38	+0.0011	+0.0012	(1)
2452615.6901	II	569.5	-0.0026	-0.0014	(1)
2452734.5230	II	841.5	-0.0037	-0.0019	(1)
2452997.9701	II	1444.5	-0.0011	+0.0020	(2)
2453739.3679	II	3141.5	-0.0051	+0.0021	(1)
2453766.2352	I	3203	-0.0065	+0.0009	(1)
2454115.5254	II	4002.5	-0.0096	-0.0006	(3)
2454195.4731	II	4185.5	-0.0127	-0.0027	(3)
2454492.3408	I	4865	-0.0116	+0.0004	(1)
2454494.3058	II	4869.5	-0.0126	-0.0006	(1)
2454574.0379	I	5052	-0.0129	-0.0003	(1)
2454809.3015	II	5590.5	-0.0144	-0.0002	(1)
2454887.2866	I	5769	-0.0141	+0.0007	(1)
2454937.0903	I	5883	-0.0158	-0.0007	(1)
2455296.2123	I	6705	-0.0171	+0.0007	(1)
2455311.0660	I	6739	-0.0177	+0.0002	(1)

Note. — References in Table 9:

(1) The present authors; (2) Maciejewski & Karska (2004); (3) Hubscher et al. (2009).

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